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Ogiwara et al.

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(54) **MASTER CYLINDER APPARATUS**

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B60T 8/00 (2006.01)

(52) **U.S. Cl.** **60/568**; 60/588

(58) **Field of Classification Search** 60/568, 60/570, 588, 566, 562

See application file for complete search history.

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(57) **ABSTRACT**

A master cylinder apparatus for a BBW system is provided, which eliminates a risk of brake delay, even with the use of a plunger-type master cylinder, and which therefore is able to achieve a reduction in size of a master cylinder. The master cylinder apparatus comprises a tandem-type master cylinder connected to wheel cylinders through fail-safe valves and a stroke simulator for ensuring a desired stroke of a brake pedal upon receiving a brake fluid introduced from a fluid pressure chamber in the master cylinder. The master cylinder is arranged in the form of a plunger-type master cylinder in which cup seals are provided on an inner surface of a bore of the cylinder body. A spring force of a second return spring for a secondary piston is set to be larger than that of a first return spring for a primary piston. A retracted position of the secondary piston is limited by a stopper pin extending through an oblong hole formed in the secondary piston.

4 Claims, 8 Drawing Sheets

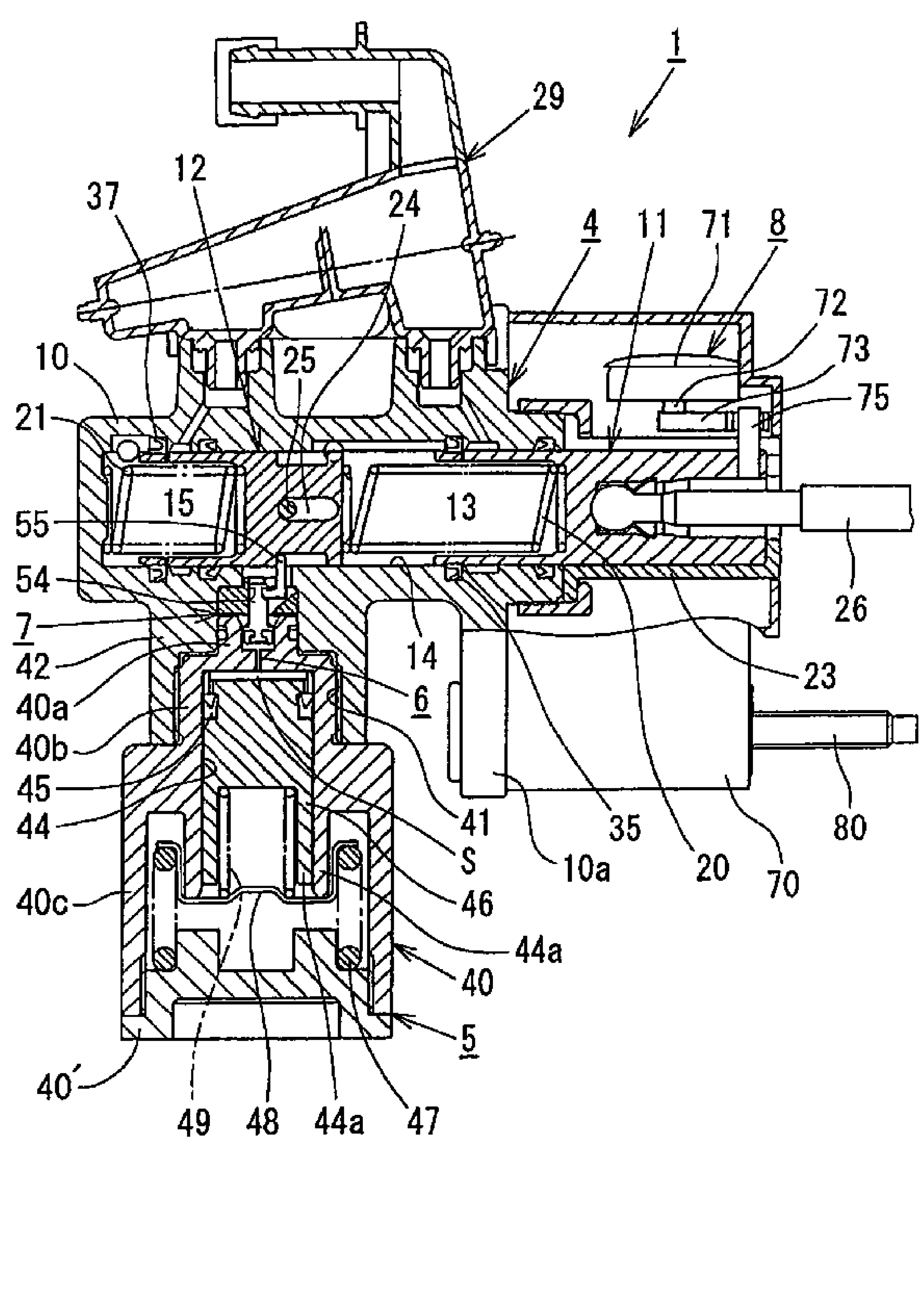
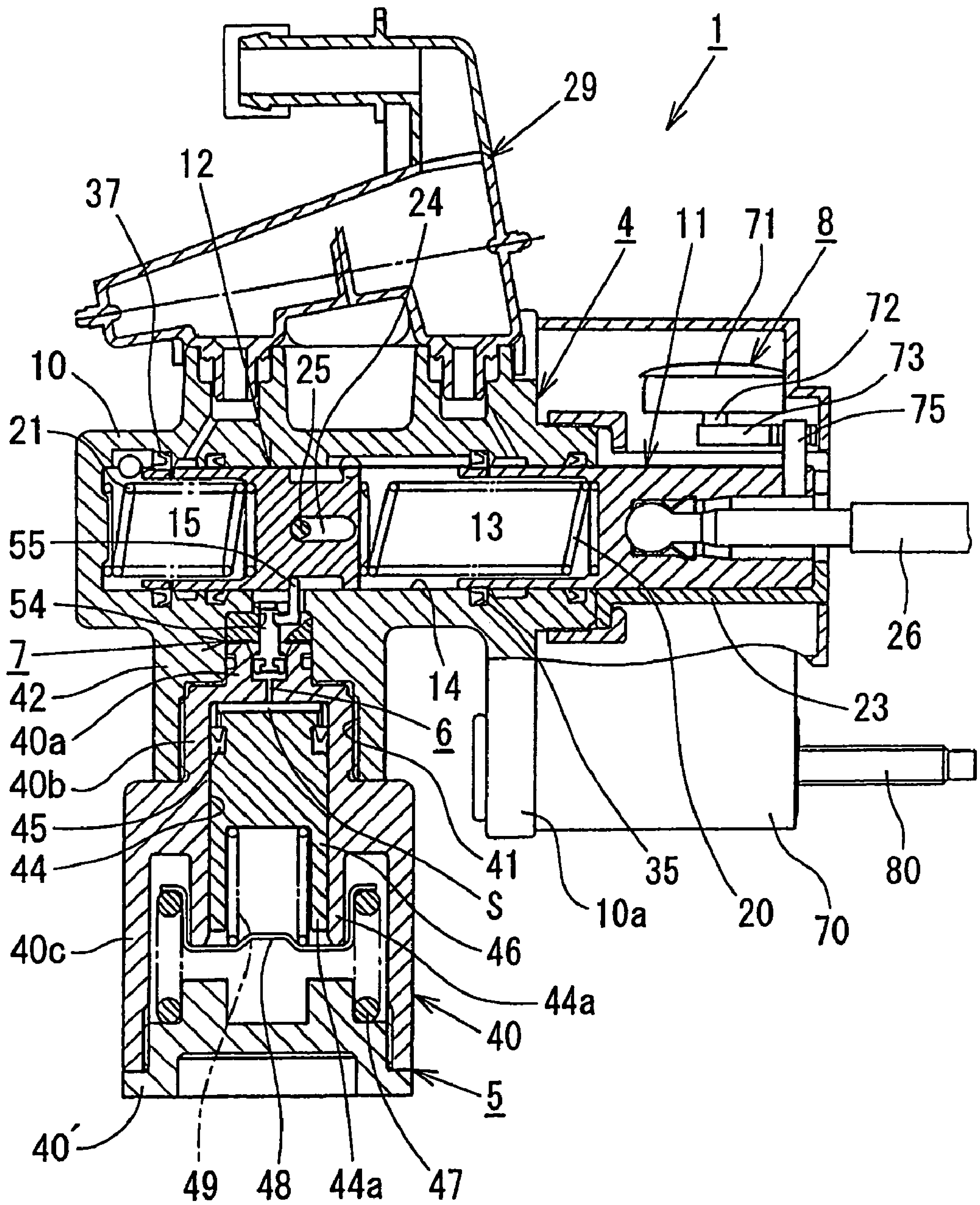


Fig.1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40c
40'
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44a
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Fig.2

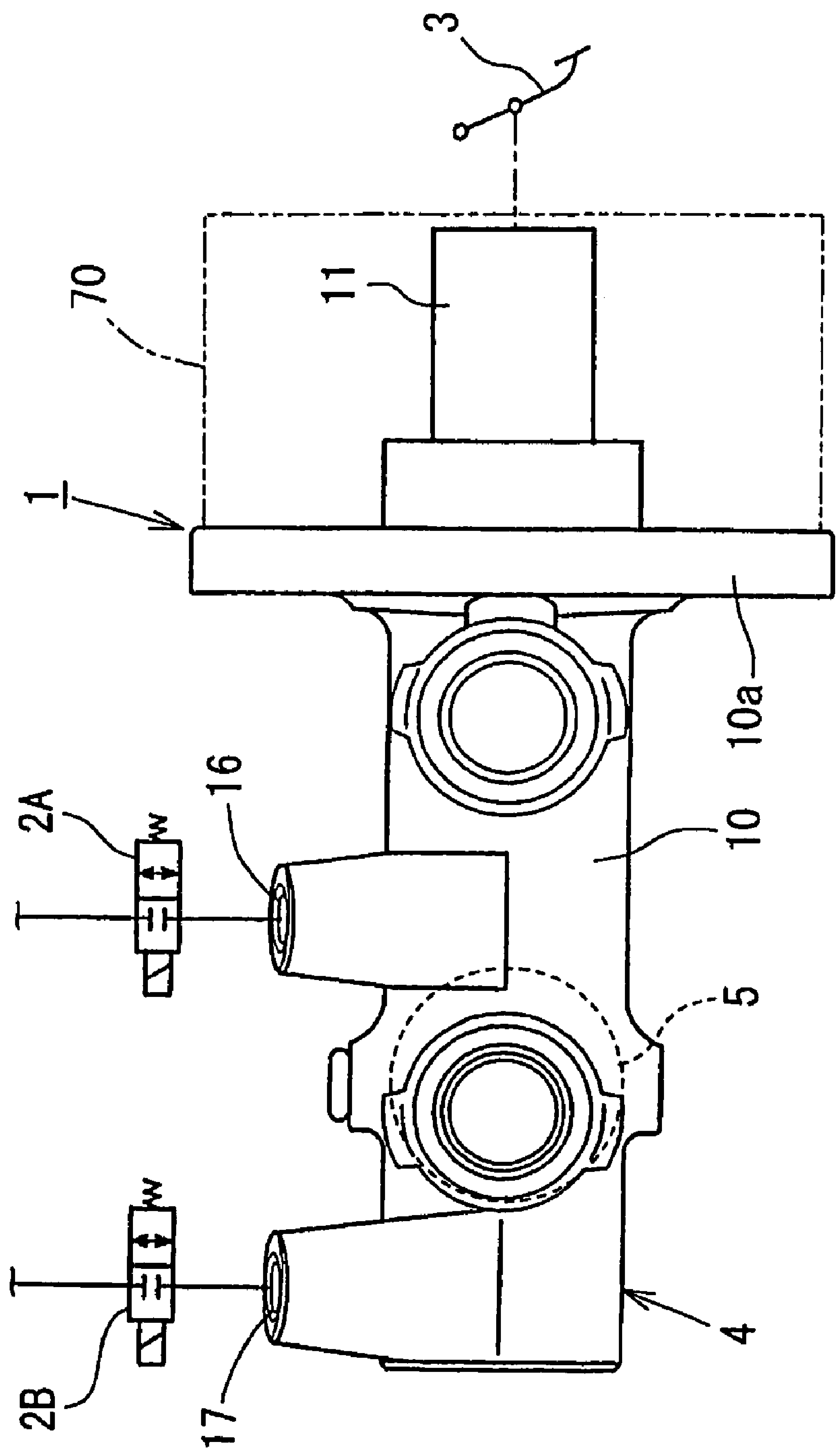
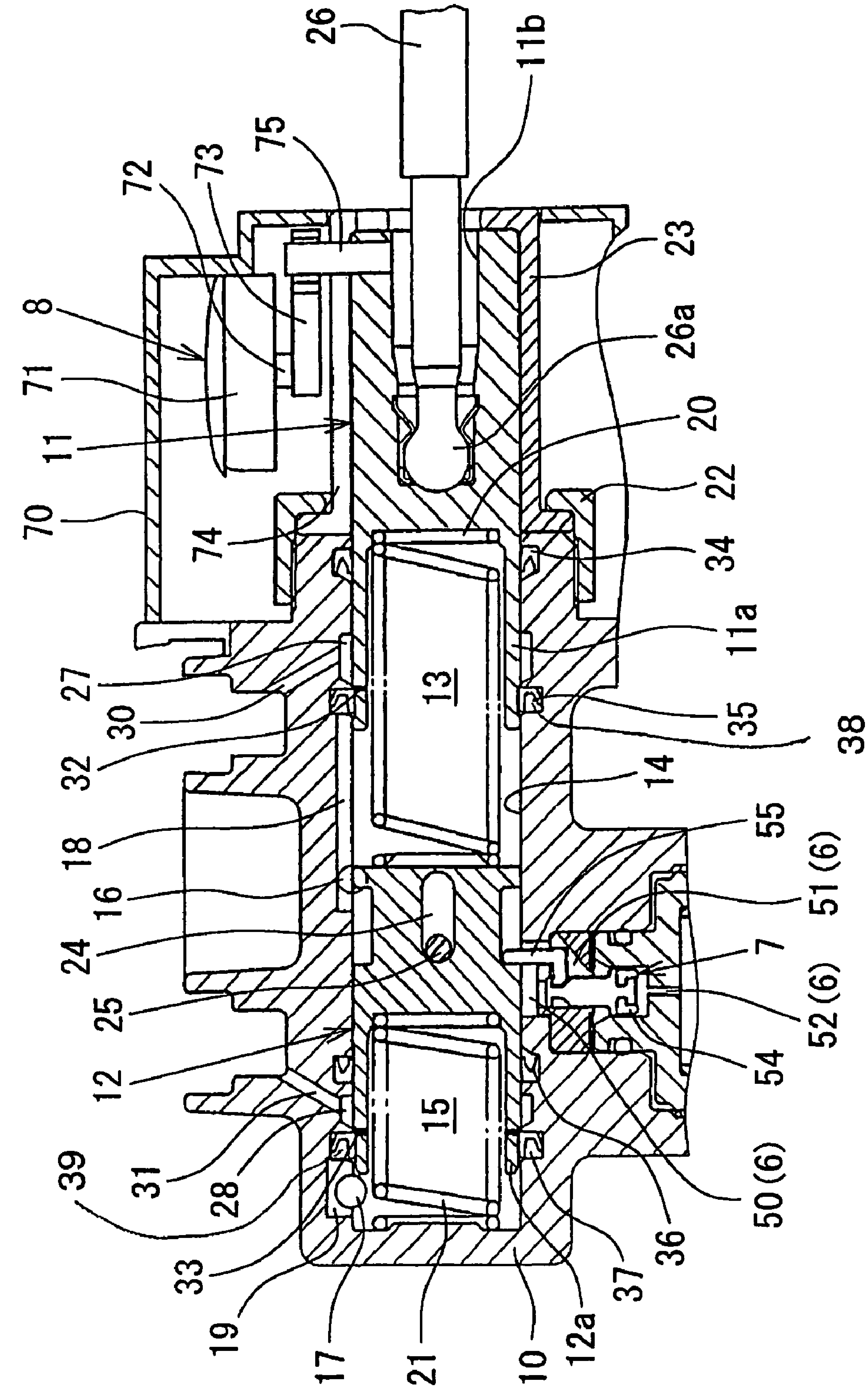


Fig.3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51 (6)
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52 (6)
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50 (6)
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17
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10
12a

Fig.4

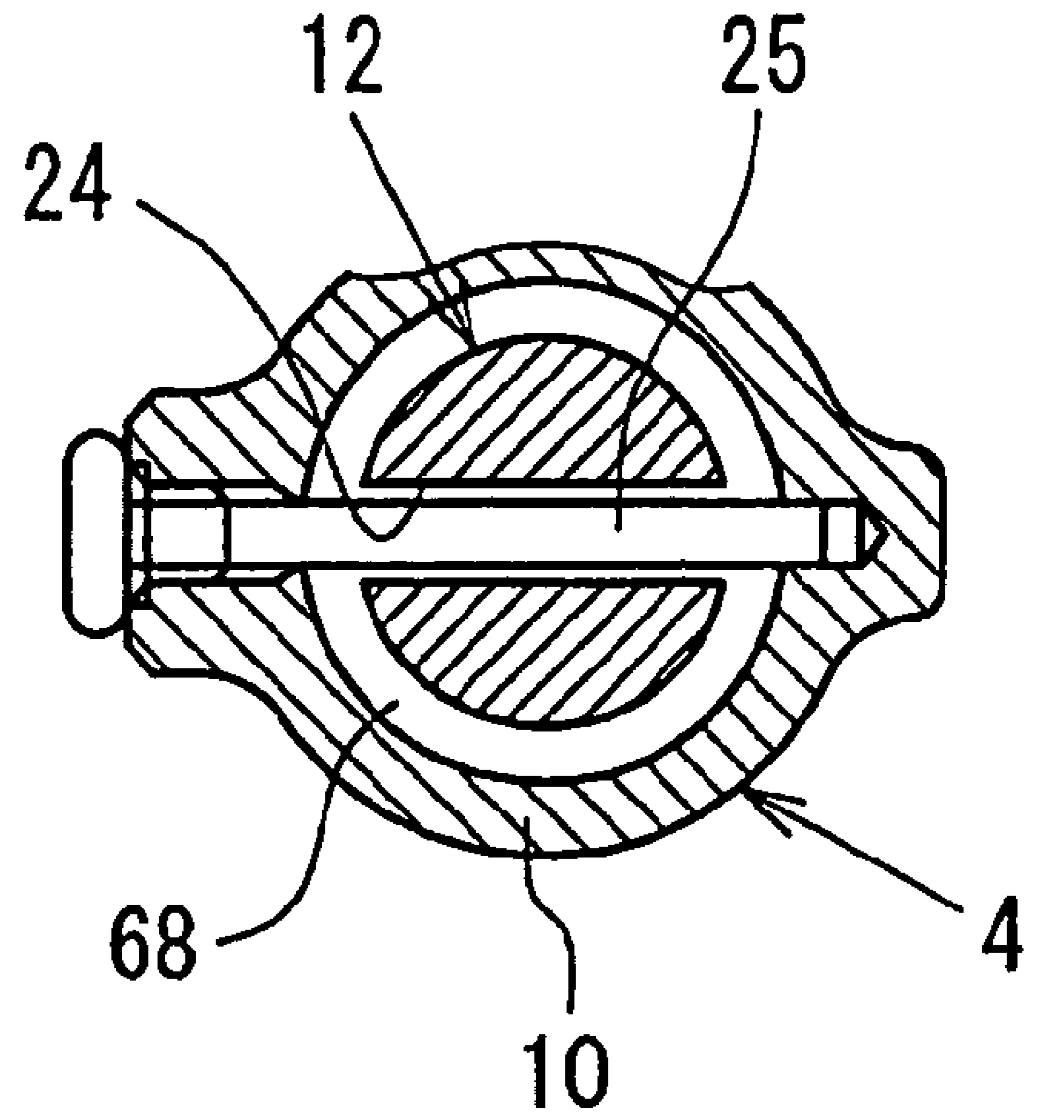

Fig.5

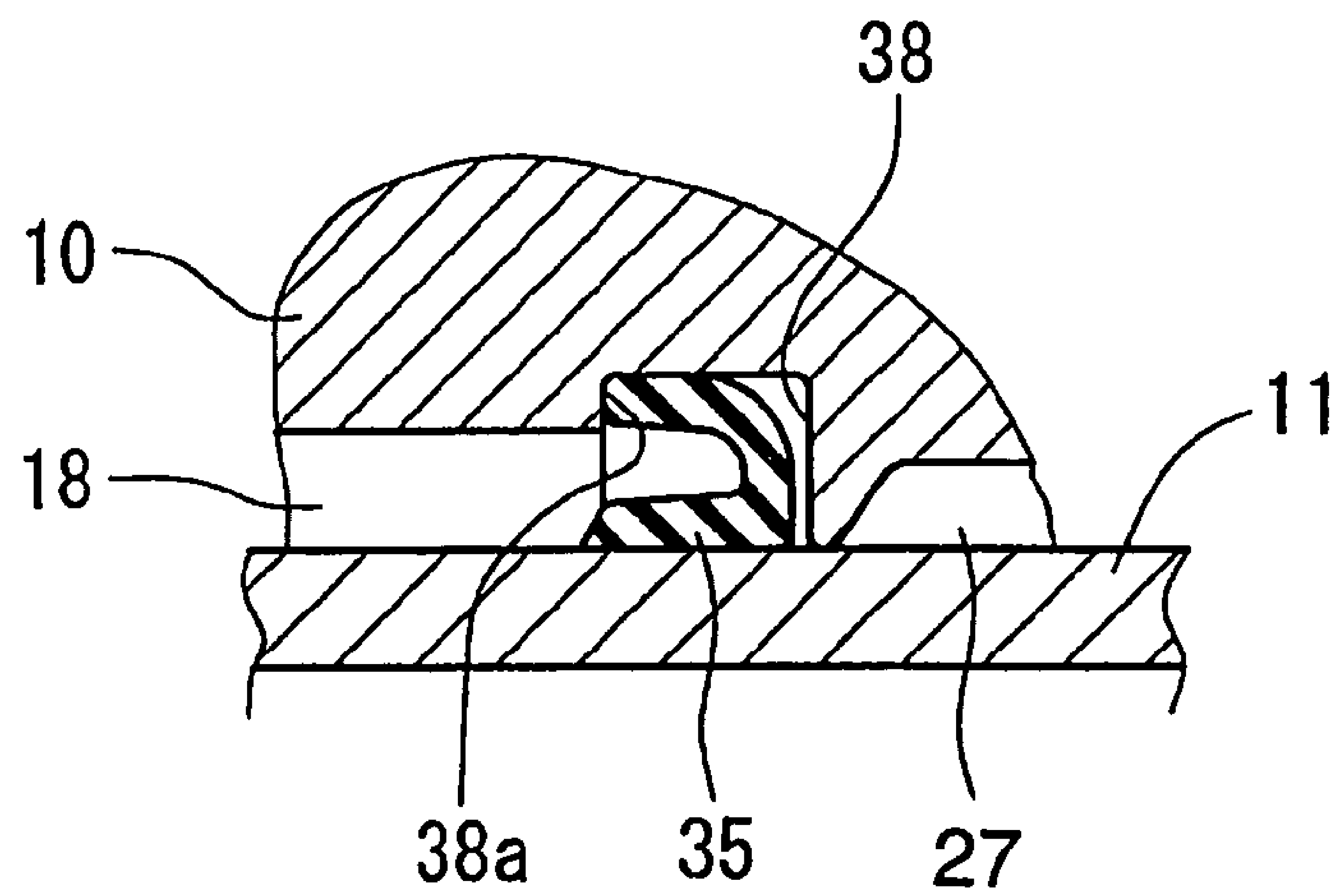

Fig.6

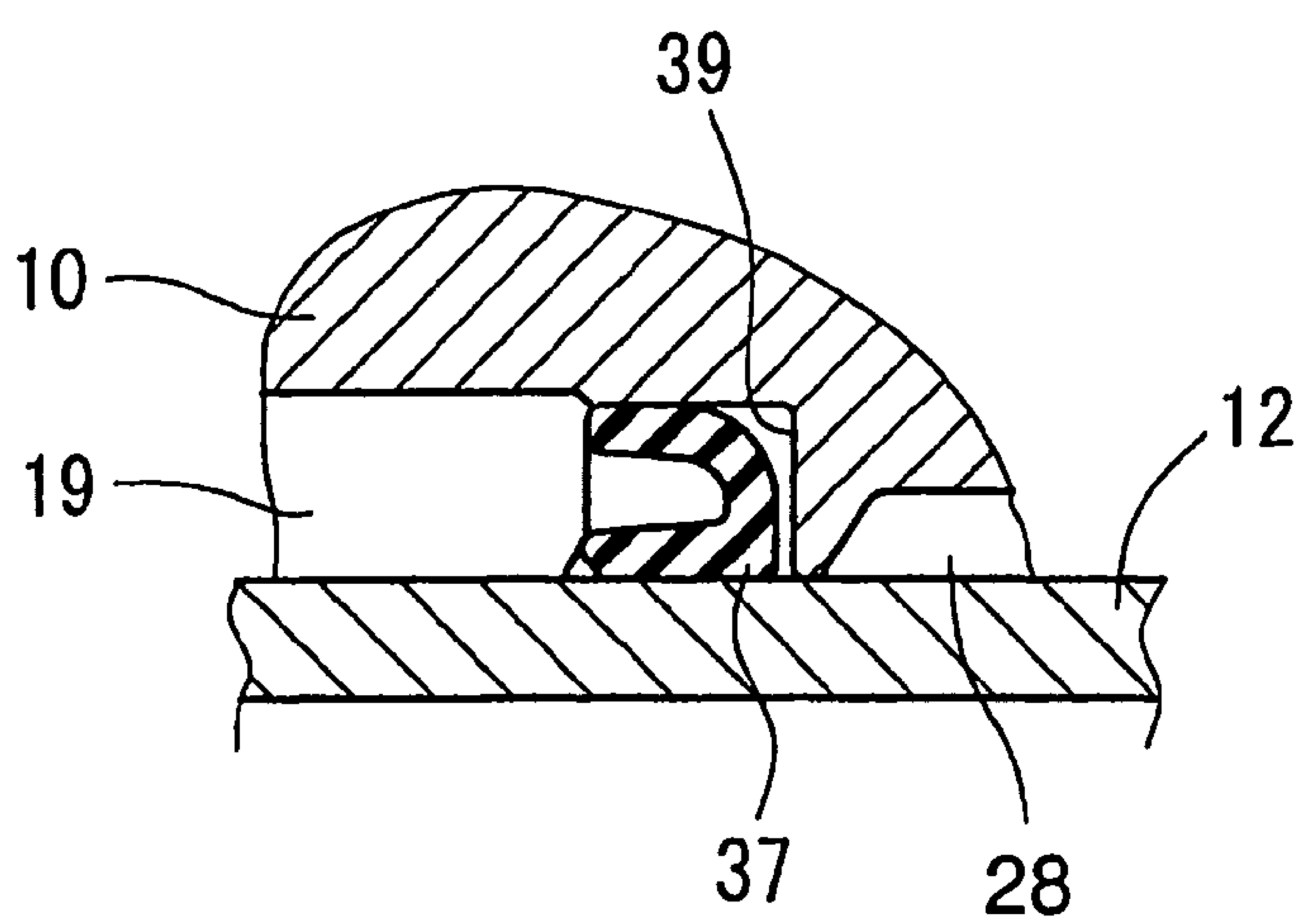

Fig.7

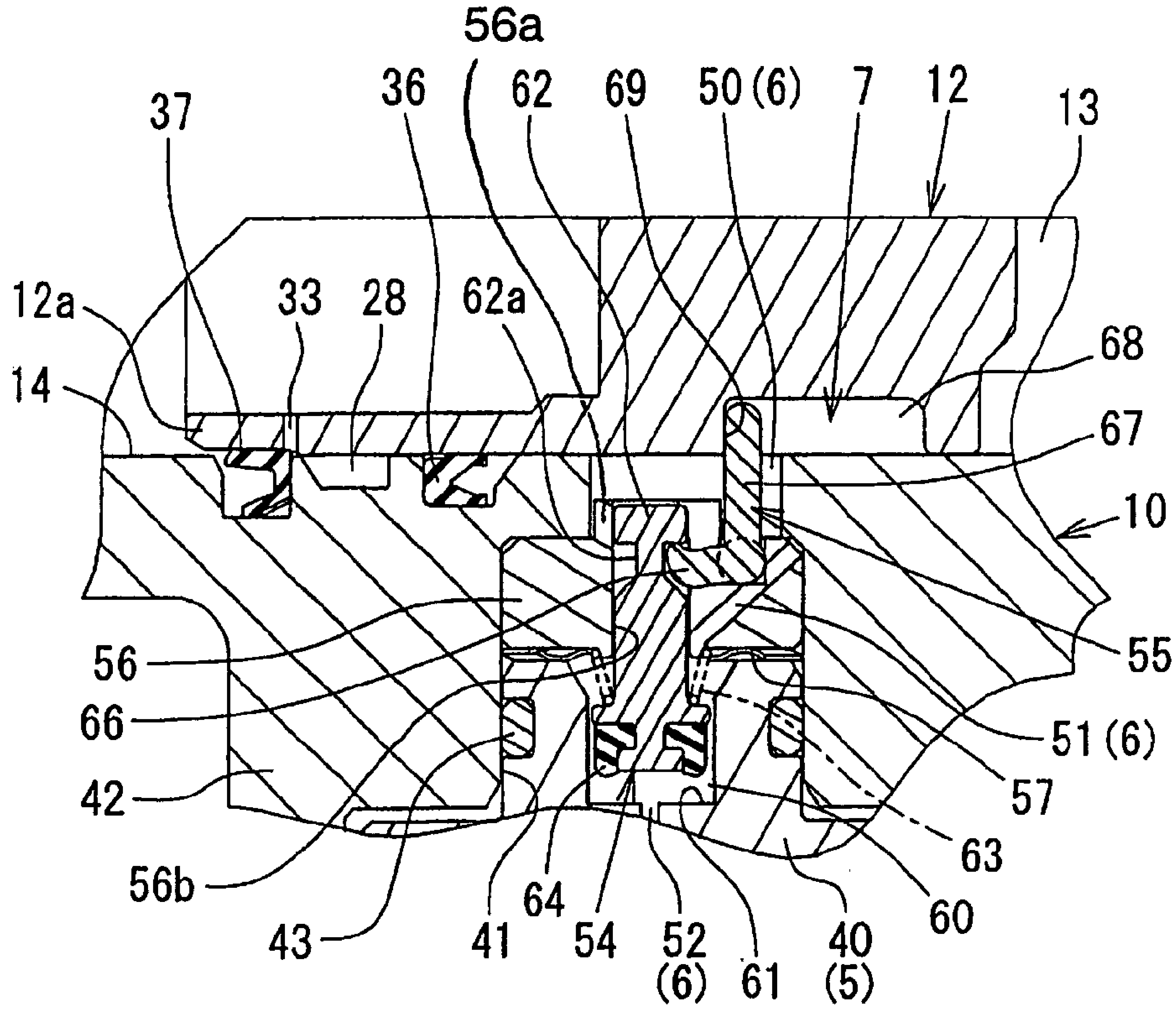
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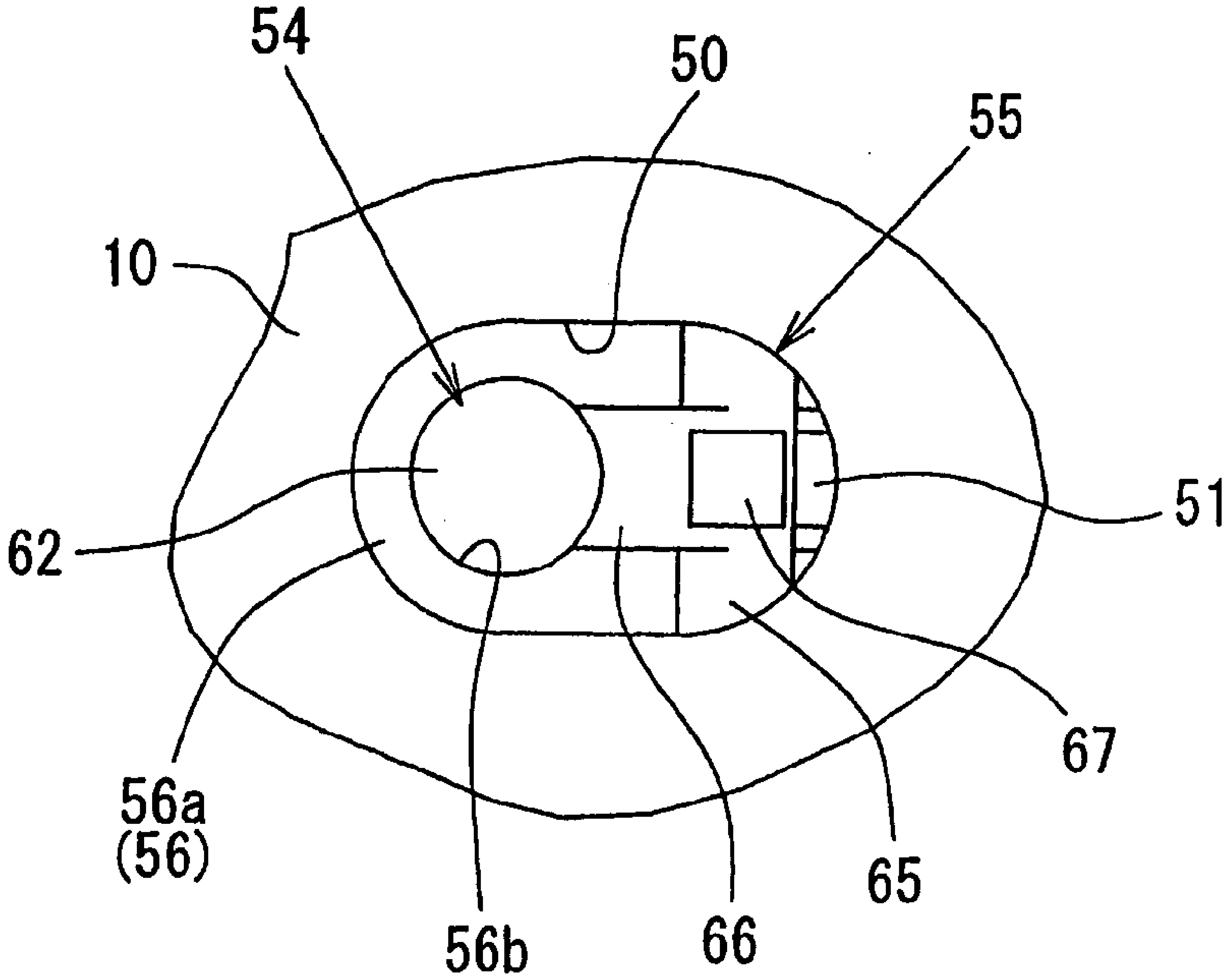
Fig.8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56b
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Fig.9

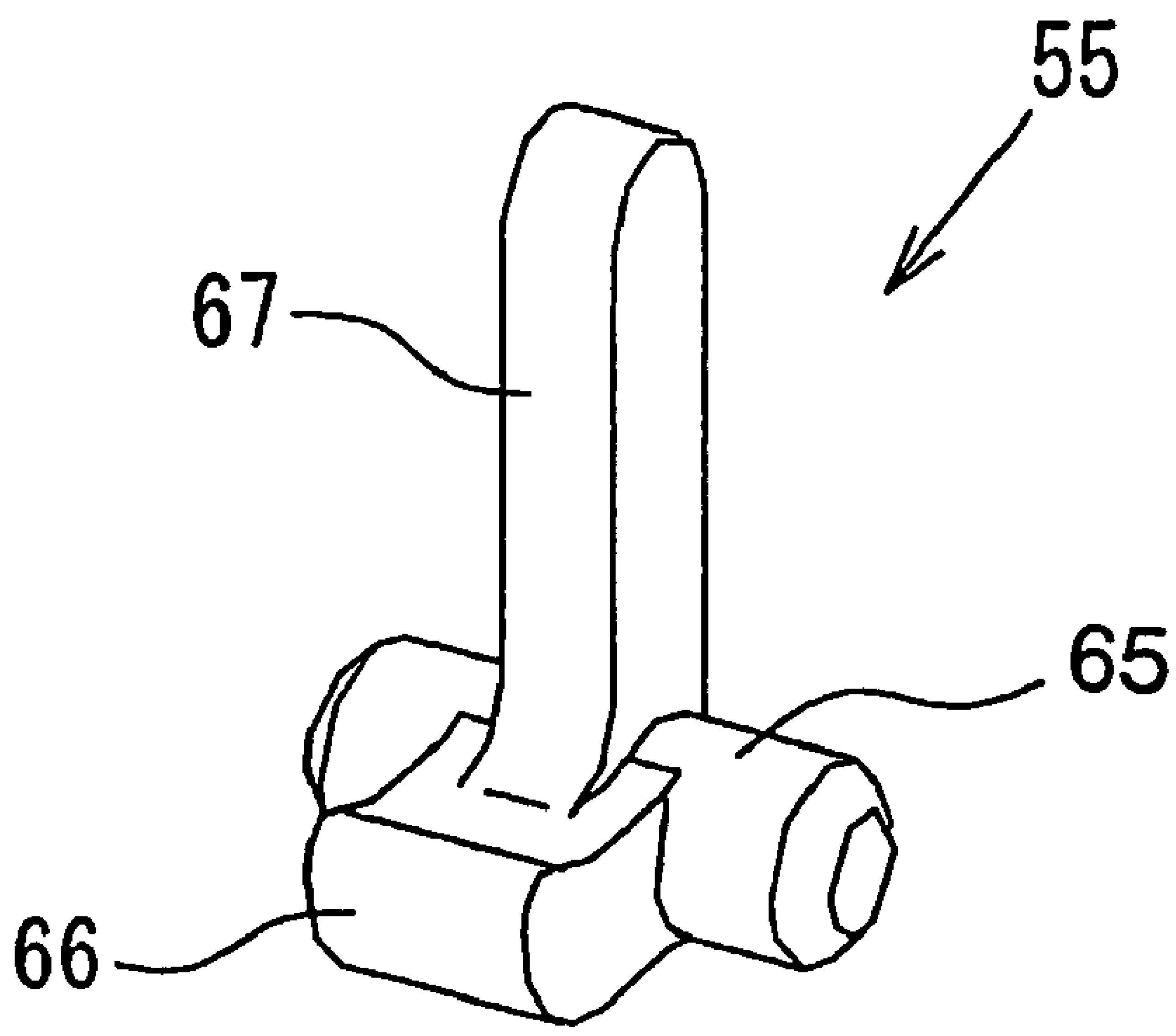
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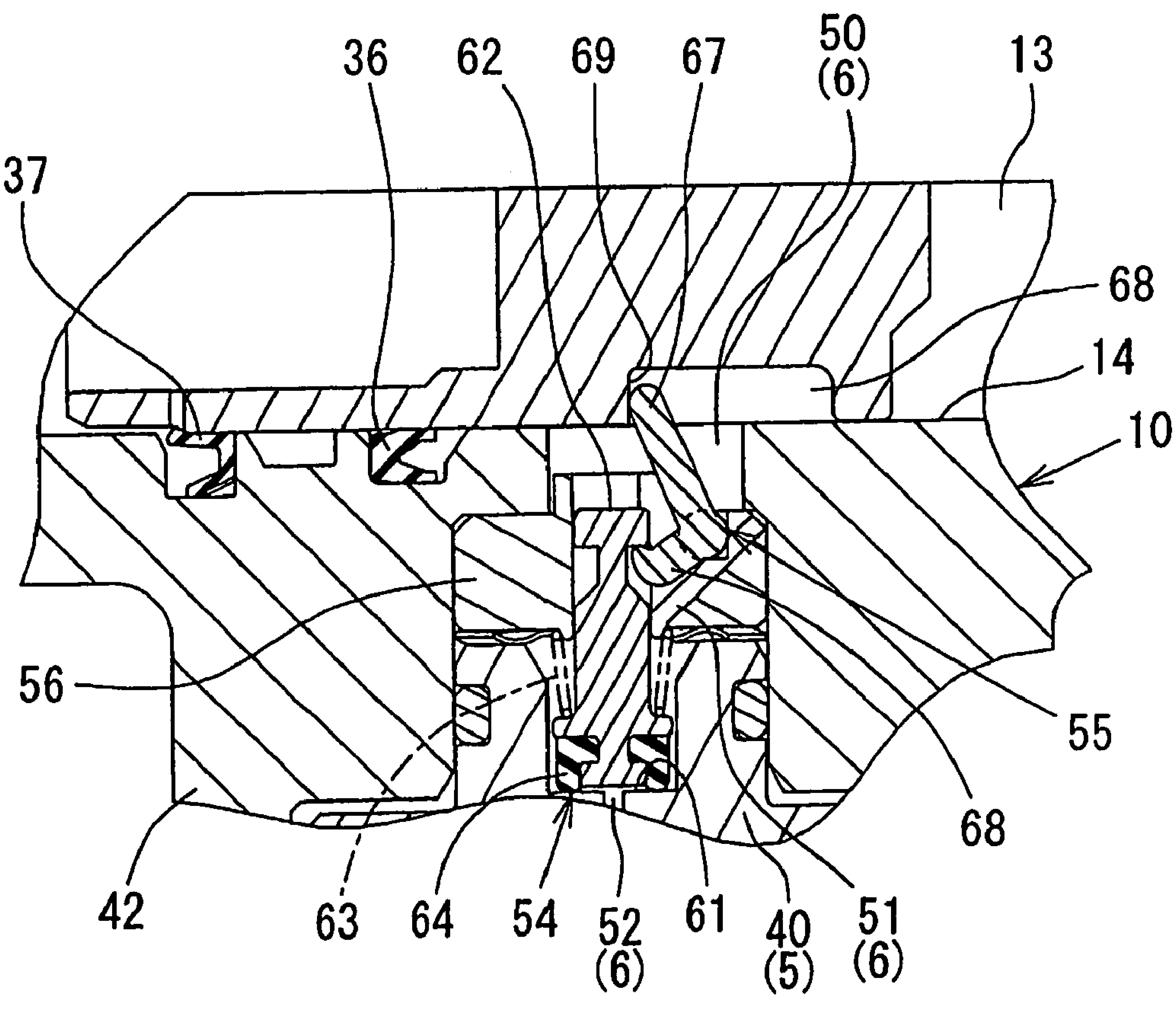
Fig.10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61
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(5)
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(6)

Fig. 11

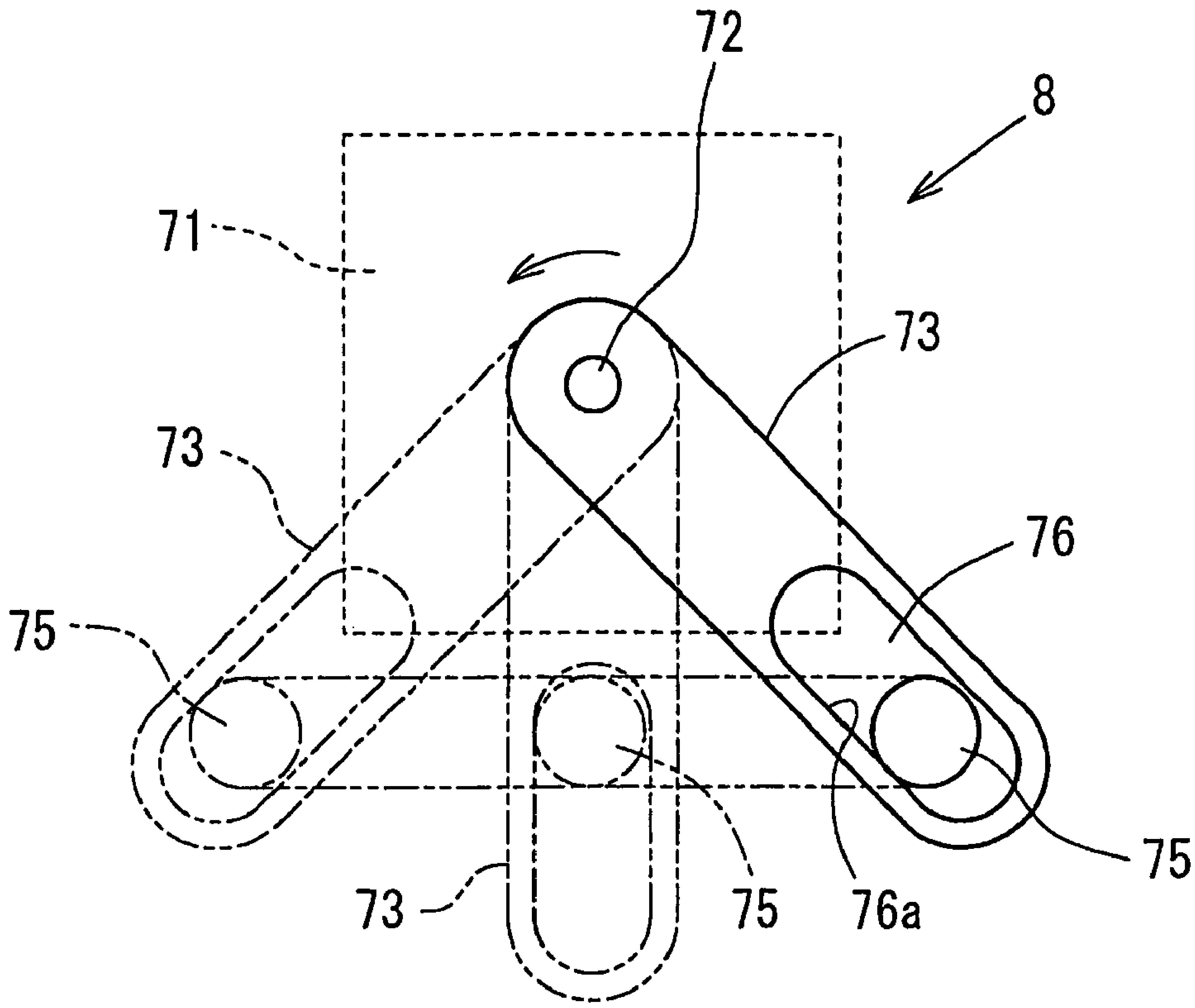


Fig. 12

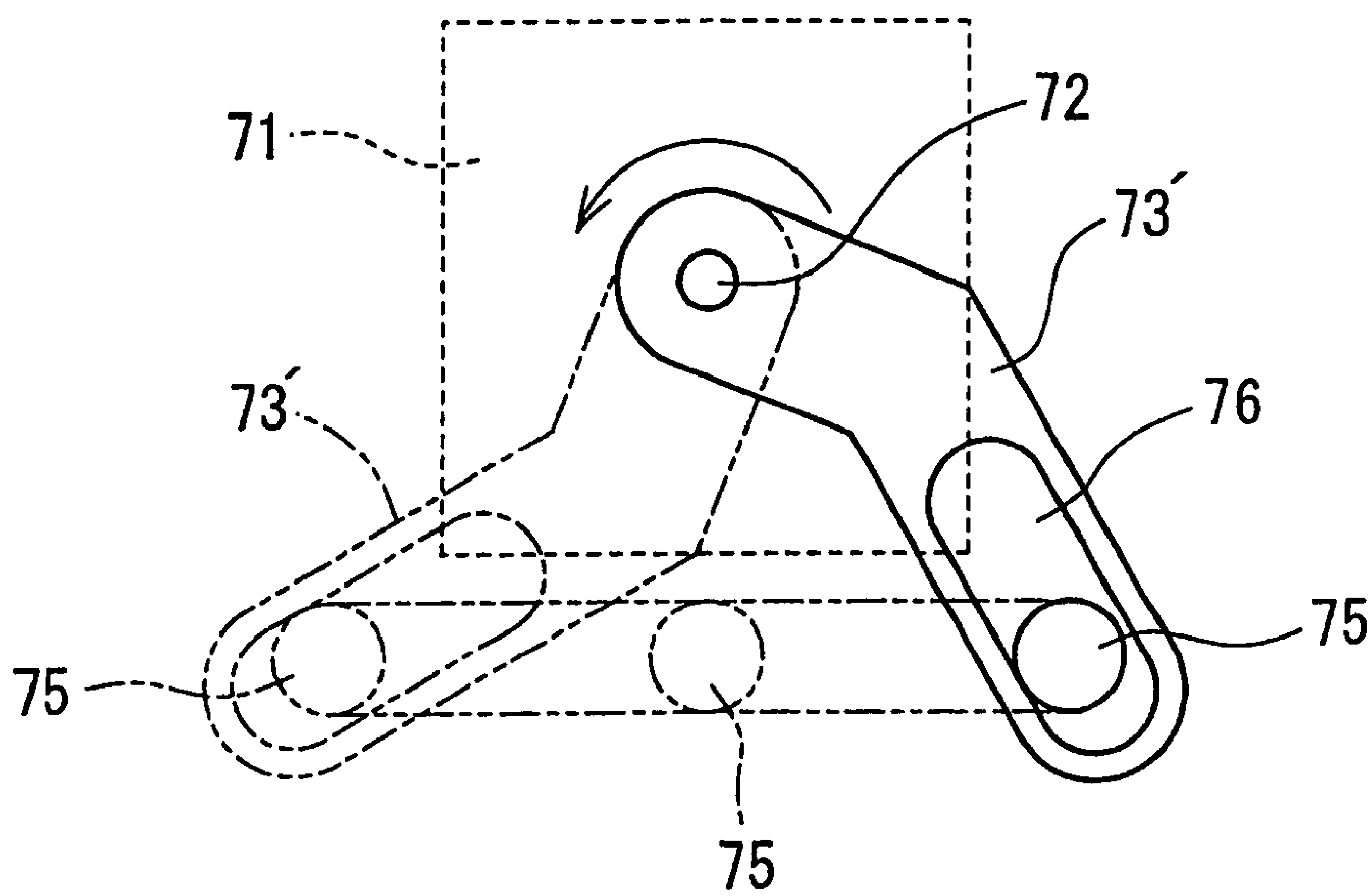


Fig. 13

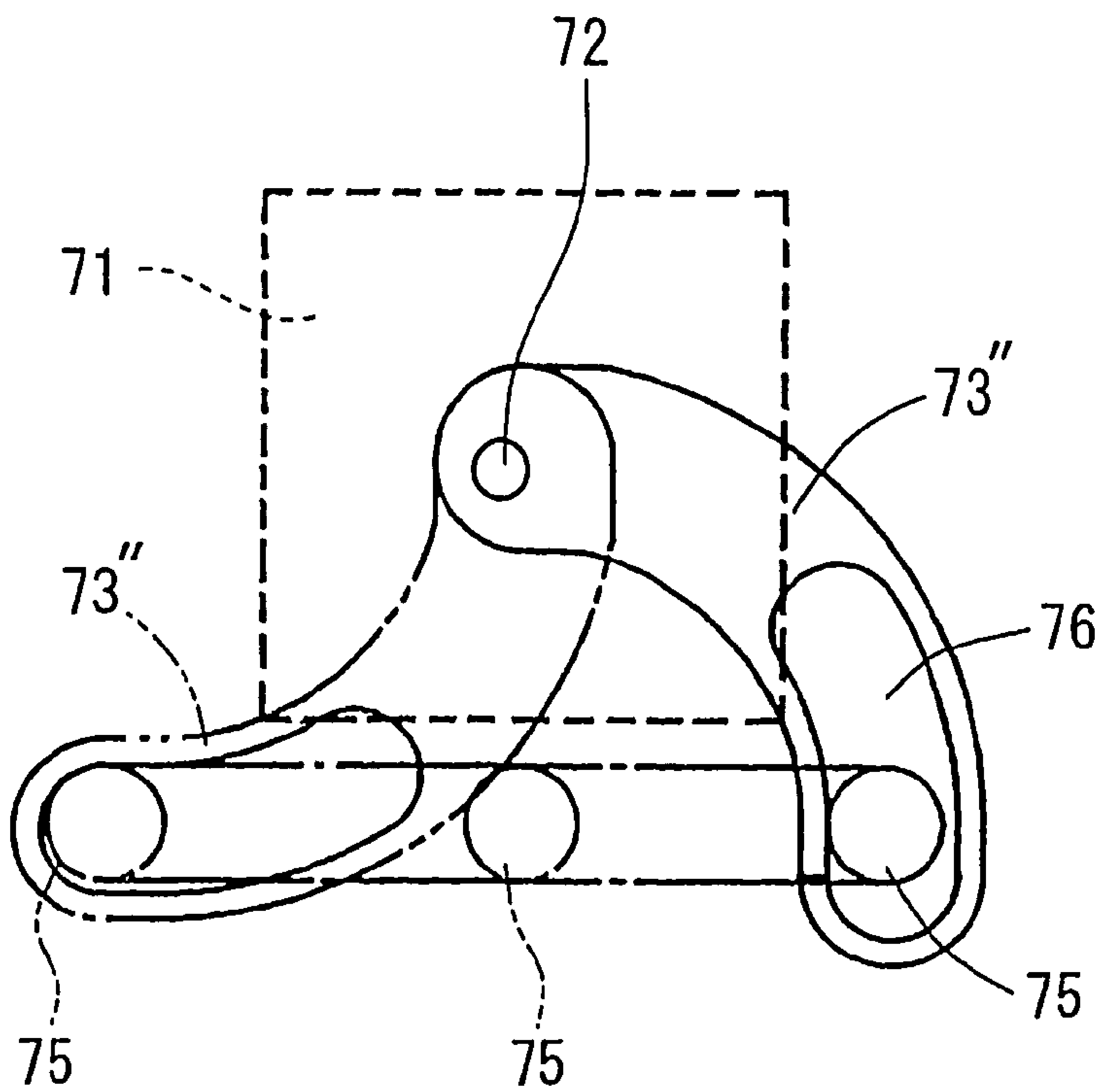
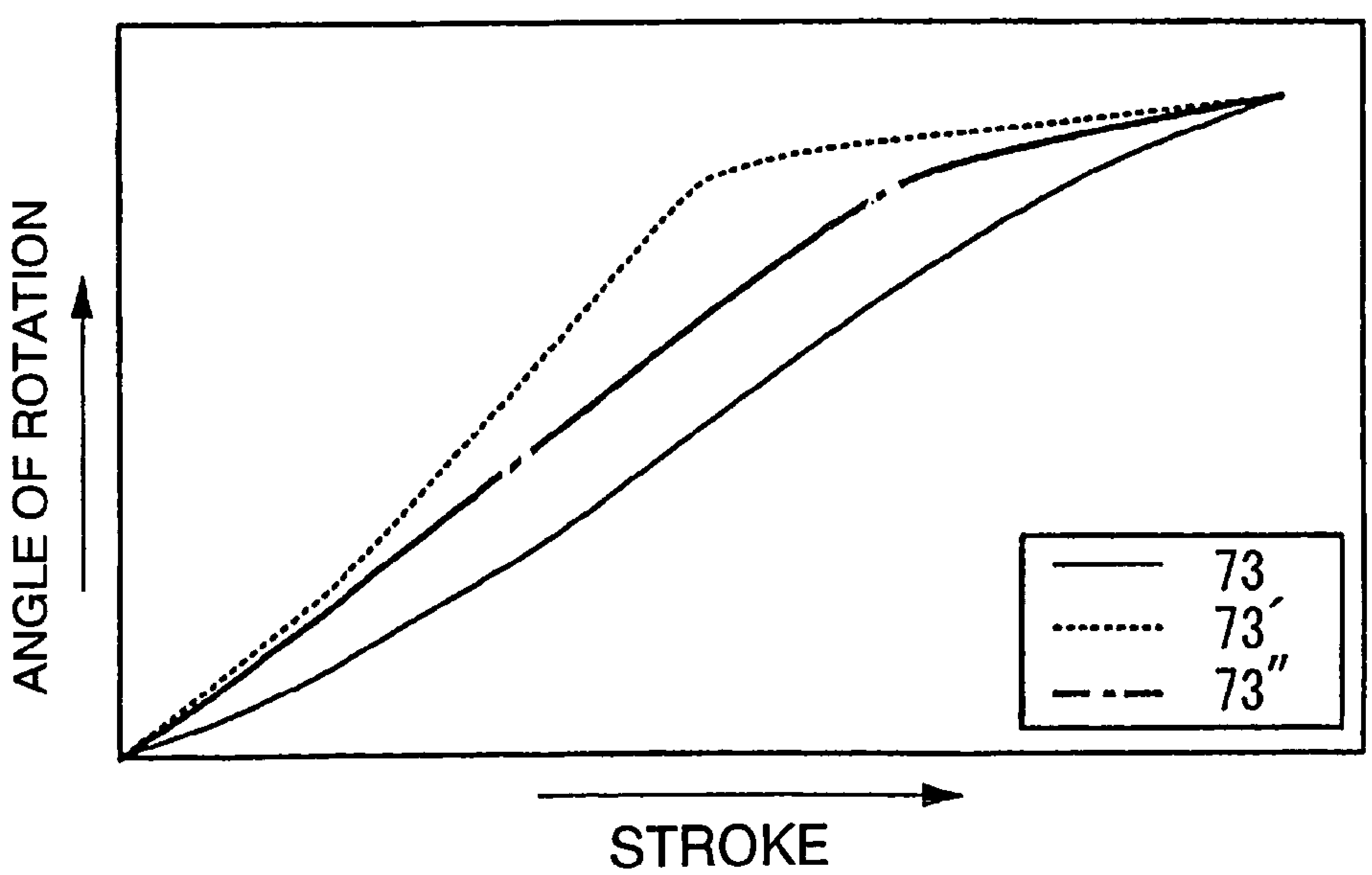


Fig. 14



MASTER CYLINDER APPARATUS

BACKGROUND OF THE INVENTION

The present invention relates to a brake system for an automobile. More specifically, the present invention relates to a master cylinder apparatus used in a brake fluid pressure controlling system for electrically controlling a fluid pressure supplied to wheel cylinders; i.e., a so-called brake-by-wire (BBW) system.

A master cylinder apparatus for a BBW system comprises a master cylinder adapted to be connected to wheel cylinders through fail-safe valves and a stroke simulator for ensuring a desired stroke of a brake pedal upon receiving a brake fluid introduced from the master cylinder. In the event of failure of the BBW system, the fail-safe valves are opened, and the fluid pressure generated in the master cylinder is supplied to the wheel cylinders.

This type of related art is disclosed in, for example, U.S. Pat. No. 6,192,685 B1.

However, the master cylinder apparatus of U.S. Pat. No. 6,192,685 B1 is configured such that supply of brake fluid from a reservoir to a primary-side pressure chamber and a secondary-side pressure chamber is controlled by means of a center valve. Consequently, axial dimensions of the primary piston and the secondary piston are large, and an overall size of a master cylinder is also large.

To counter this problem, it has been suggested to use a plunger-type master cylinder in which cup seals are provided on an inner surface of a bore of a cylinder body, so as to seal outer circumferential surfaces of a primary piston and a secondary piston, each of which is subject to a sliding movement in the cylinder body. In the case of a master cylinder apparatus for a BBW system, it is generally required to set a spring force of a return spring for biasing a secondary piston to be larger than that of a return spring for biasing a primary piston, so as to limit a force that a driver is required to apply to a brake pedal. In such a configuration, since a spring force for biasing the secondary piston must be made large, and a return position (a retracted position) of the secondary piston during non-braking is therefore variable, a possibility exists that in the event of a failure of the BBW system, an invalid stroke for operating the secondary piston will be large, resulting in a delay in braking.

SUMMARY OF THE INVENTION

The present invention has been made with a view to overcoming the drawbacks of the prior art, as stated above. It is therefore an object of the present invention to provide a master cylinder apparatus which eliminates a risk of brake delay in the event of failure of a BBW system, even with the use of a plunger-type master cylinder, and which therefore is able to safely achieve a reduction in size of a master cylinder.

In order to achieve the above-mentioned object, the present invention provides a master cylinder apparatus comprising:

a tandem-type master cylinder adapted to be connected to wheel cylinders through fail-safe valves; and

a stroke simulator for ensuring a desired stroke of a brake pedal upon receiving a brake fluid introduced from a primary-side fluid pressure chamber formed in the master cylinder,

wherein:

the tandem-type master cylinder comprises:

a cylinder body;

a primary piston and a secondary piston arranged in an axial direction of the cylinder body and being capable of sliding movement in the cylinder body;

the primary-side fluid pressure chamber, which is defined between the primary piston and the secondary piston;

a secondary-side fluid pressure chamber defined between the secondary piston and the cylinder body;

a first circumferential groove and a second circumferential groove formed in an inner surface of a bore of the cylinder body, the first circumferential groove and the second circumferential groove being spaced apart from each other in the axial direction of the cylinder body;

a first cup seal provided in the first circumferential groove and adapted to seal an outer circumferential surface of the primary piston;

a second cup seal provided in the second circumferential groove and adapted to seal an outer circumferential surface of the secondary piston;

a first return spring provided in the primary-side fluid pressure chamber so as to bias the primary piston in a direction for retraction;

a second return spring provided in the secondary-side fluid pressure chamber so as to bias the secondary piston in the direction for retraction; and

a limiting means provided in the cylinder body so as to limit a retracted position of the secondary piston.

In this master cylinder apparatus, the second return spring for biasing the secondary piston may have a larger spring force than the first return spring for biasing the primary piston. The limiting means may comprise a stopper pin which extends across the bore of the cylinder body, the stopper pin being provided in an oblong hole extending through the secondary piston.

In the master cylinder apparatus arranged as mentioned above, there is provided a limiting means adapted to limit a retracted position of a secondary piston; as a result of which a retracted position of the secondary piston remains constant, even in a case that a spring force of a return spring for biasing the secondary piston is larger than that of a return spring for biasing a primary piston. By this means, an invalid stroke of the secondary piston can be markedly reduced. Further, by use of a plunger-type master cylinder, an axial dimension of a master cylinder can also be reduced.

Since the retracted position of the secondary piston is limited by the limiting means, an invalid stroke of the secondary piston is reduced. Therefore, in the event of failure of the BBW system, brake delay does not occur, and the apparatus is made highly reliable. Further, since an axial dimension of a master cylinder is reduced by use of a plunger-type master cylinder, the master cylinder apparatus is easily mountable on a vehicle.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-sectional view showing an entire structure of a master cylinder apparatus according to an embodiment of the present invention.

FIG. **2** is a side view showing the entire structure of the master cylinder apparatus of FIG. **1**.

FIG. **3** is a cross-sectional view showing a structure of a master cylinder of the master cylinder apparatus of FIG. **1**.

FIG. **4** is an enlarged cross-sectional view of a part of the master cylinder of FIG. **3**.

FIG. **5** is a cross-sectional view showing a primary-side cup seal in assembled position.

FIG. **6** is a cross-sectional view showing a secondary-side cup seal in assembled position.

FIG. **7** is a cross-sectional view showing a structure of an opening/closing means of the master cylinder apparatus of FIG. **1**.

FIG. **8** is a plan view of the opening/closing means shown in FIG. **7**, as viewed from inside a bore of the master cylinder.

FIG. **9** is a perspective view of a rocking lever of the opening/closing means of FIG. **7**.

FIG. **10** is a cross-sectional view showing an operation of the opening/closing means of FIG. **7**.

FIG. **11** is a schematic diagram showing a structure of a stroke sensor of the master cylinder apparatus of FIG. **1**.

FIG. **12** is a schematic diagram showing a modified example of a stroke sensor of the master cylinder apparatus.

FIG. **13** is a schematic diagram showing another modified example of a stroke sensor of the master cylinder apparatus.

FIG. **14** is a graph indicating a relationship between the stroke and the angle of rotation in each of the stroke sensors shown in FIGS. **11** to **13**.

DETAILED DESCRIPTION OF THE INVENTION

Hereafter, an embodiment of the present invention is described, with reference to the accompanying drawings.

FIGS. **1** and **2** show the entire structure of a master cylinder apparatus according to an embodiment of the present invention. A master cylinder apparatus **1** is used in a BBW system described above. The master cylinder apparatus **1** is connected to wheel cylinders (not shown) through fail-safe valves **2**A and **2**B. The master cylinder apparatus **1** comprises a tandem-type master cylinder **4** for generating a fluid pressure corresponding to a force applied to a brake pedal **3**, and a stroke simulator **5** for ensuring a desired stroke of the brake pedal **3**. The stroke simulator **5** is externally mounted on a cylinder body **10** of the master cylinder **4**. A first fluid pressure chamber (a primary-side fluid pressure chamber) **13** is defined between a primary piston **11** and a secondary piston **12** provided in the master cylinder **4**. When the brake pedal **3** is operated, a brake fluid in the first fluid pressure chamber **13** is introduced into the stroke simulator **5**, to thereby ensure a desired stroke of the brake pedal **3**.

The master cylinder apparatus **1** further comprises an opening/closing means **7** and a stroke sensor **8**. The opening/closing means **7** is provided in a simulator passage **6** which allows communication between the first fluid pressure chamber **13** in the master cylinder **4** and the stroke simulator **5**. The stroke sensor **8** is adapted to detect a stroke of the primary piston **11** (a piston stroke), which moves in the master cylinder **4** in accordance with the movement of the brake pedal **3**. The BBW system comprises a fluid pressure controlling means including a fluid pressure source, a fluid pressure control valve and an electronic control unit, etc., in addition to the master cylinder apparatus **1**. Normally, the fluid pressure controlling means controls a fluid pressure supplied to the wheel cylinders, on the basis of a detection signal emitted from the stroke sensor **8**.

The master cylinder **4** is arranged in the form of a plunger-type master cylinder. The cylinder body **10** is arranged in the form of a cylinder having one end closed, as shown in FIG. **3**. The primary piston **11** and the secondary piston **12** are slidably provided in a bore **14** of the cylinder body **10**.

A forward end (an end for insertion into the bore **14**) of the primary piston **11** forms a cup-like portion **11***a*. The first fluid pressure chamber **13** is defined between the cup-like portion **11***a* of the primary piston **11** and the secondary piston **12**. A forward end of the secondary piston **12** also forms a cup-like portion **12***a*. A second fluid pressure chamber (a secondary-side fluid pressure chamber) **15** is defined between the cup-like portion **12***a* and the closed end of the cylinder body **10**. The cylinder body **10** includes a first discharge port **16** for supplying brake fluid from the first fluid pressure chamber **13** to the corresponding wheel cylinders, and a second discharge port **17** for supplying brake fluid from the second fluid pressure chamber **15** to the corresponding wheel cylinders. The first discharge port **16** opens into a longitudinal groove **18** formed in an inner surface of the bore **14** of the cylinder body **10**; and the second discharge port **17** opens into a longitudinal groove **19** formed in the inner surface of the bore **14** of the cylinder body **10**.

A first return spring **20** is provided between a bottom of the cup-like portion **11***a* of the primary piston **11** and the secondary piston **12**. A second return spring **21** is provided between a bottom of the cup-like portion **12***a* of the secondary piston **12** and the closed end of the cylinder body **10**. Normally, spring forces of the first and second return springs **20** and **21** bias each of the pistons **11** and **12** in a direction away from the bore **14**.

The spring force of the second return spring **21** for biasing the secondary piston **12** is set to be larger than that of the first return spring **20** for biasing the primary piston **11**.

A rear end portion of the cylinder body **10** is connected to a piston guide **23** in the form of a cylinder having one end closed, by means of a retaining member **22** threadably engaged with the rear end portion of the cylinder body **10**. A bottom plate of the piston guide **23** prevents the primary piston **11** from separating from the bore **14**, while limiting a retracted position of the primary piston **11**. A retracted position of the secondary piston **12** is limited by a stopper pin (a limiting means) **25** which is inserted into a diametrical hole (an oblong hole) **24** extending through a solid portion of the secondary piston **12**. As shown in FIG. **4**, the stopper pin **25** extends across the bore **14**, with a base end portion thereof being threadably engaged with a wall of the cylinder body **10**.

A rear end (opposite to the end for insertion) of the primary piston **11** includes a recess **11***b* extending along the axis of the primary piston **11**. An input shaft **26** extending from the brake pedal **3** is inserted into the recess **11***b*. The input shaft **26** is locked in the recess **11***b* in a state such that a spherical portion **26***a* formed at a forward end of the input shaft **26** abuts against a bottom part of the recess **11***b*. The primary piston **11** is adapted to advance toward a closed end of the bore **14** under a force applied from the brake pedal **3** through the input shaft **26**.

The inner surface of the bore **14** of the cylinder body **10** includes two annular grooves **27** and **28**. The annular groove **27** faces the primary piston **11**, and the annular groove **28** faces the secondary piston **12**. A reservoir port **30** communicating with a reservoir **29** mounted on the top of the cylinder body **10** opens into the annular groove **27**. A reservoir port **31** communicating with the reservoir **29** opens into the annular groove **28**. The cup-like portion **11***a* of the primary piston **11** includes a supply port **32**, and the cup-like portion **12***a* of the secondary piston **12** includes a supply port **33**. When the primary piston **11** and the secondary piston **12** are located at their respective retracted positions, the supply port **32** and the supply port **33** are open to the annular groove

27 and the annular groove 28, respectively. In this state, brake fluid is supplied from the reservoir 29 to the first fluid pressure chamber 13 and the second fluid pressure chamber 15.

A pair of cup seals 34 and 35 are provided on the inner surface of the bore 14 of the cylinder body 10, with the primary-side annular groove 27 being disposed therebetween. Further, on the inner surface of the bore 14 of the cylinder body 10, a pair of cup seals 36 and 37 are provided, with the secondary-side annular groove 28 being disposed therebetween.

Of the cup seals on the primary side, the cup seal 34 located on a side of an open end of the bore 14 serves to seal the first fluid pressure chamber 13 from the outside. Of the cup seals on the secondary side, the cup seal 36 located on a side of the open end of the bore 14 serves to prevent communication between the first fluid pressure chamber 13 and the second fluid pressure chamber 15.

On the other hand, of the cup seals on the primary side, the cup seal 35 located on a side of the closed end of the bore 14 serves to prevent flow of the fluid from the first fluid pressure chamber 13 to the annular groove 27 communicated with the reservoir 29. Of the cup seals on the secondary side, the cup seal 37 located on a side of the closed end of the bore 14 serves to prevent flow of the fluid from the second fluid pressure chamber 15 to the annular groove 28 communicated with the reservoir 29.

The primary-side cup seals 34 and 35 and the secondary-side cup seals 36 and 37 are respectively provided in annular grooves formed in the inner surface of the bore 14 of the cylinder body 10. The cup seal 35 on a side of the closed end of the bore 14 is provided in an annular groove 38, which is communicated with the longitudinal groove 18 formed in the inner surface of the bore 14. The cup seal 37 on a side of the closed end of the bore 14 is provided in an annular groove 39, which is communicated with the longitudinal groove 19 formed in the inner surface of the bore 14. As shown in FIG. 5, the longitudinal groove 18, which is communicated with the annular groove 38 in which the primary-side cup seal 35 is provided, is shallower than the annular groove 38. That is, an outer circumferential edge of the cup seal 35 abuts against a front wall surface 38*a* of the annular groove 38 to limit a flow of the fluid from the annular groove 27 behind the cup seal 35 to the first fluid pressure chamber 13. In contrast, as shown in FIG. 6, the longitudinal groove 19, which is communicated with the annular groove 39 in which the secondary-side cup seal 37 is provided, has a depth equal to or slightly larger than the depth of the annular groove 39, thus allowing flow of the fluid from the annular groove 28 behind the cup seal 37 to the second fluid pressure chamber 15.

As shown in FIG. 1, the stroke simulator 5 comprises a simulator body 40 having a stepped configuration including a small-diameter portion 40*a*, an intermediate-diameter portion 40*b* and a large-diameter portion 40*c*. External threads are formed in an outer circumferential surface of the intermediate-diameter portion 40*b*. On the other hand, a boss portion 42 having a stepped inner surface defining a fitting opening 41 is projected from the cylinder body 10 of the master cylinder 4. A large-diameter portion of the fitting opening 41 has internal threads. The simulator body 40 of the stroke simulator 5 is directly connected to the cylinder body 10 by threadably engaging the intermediate-diameter portion 40*b* with the fitting opening 41 of the cylinder body 10. Thus, the simulator body 40 of the stroke simulator 5 is mounted on an exterior surface of the cylinder body 10. To connect the simulator body 40 to the cylinder body 10, the small-diameter portion 40*a* at a forward end of the simulator body 40 is press-fitted into a small-diameter portion of the fitting opening 41 through a seal member 43 (see FIG. 7).

The simulator passage 6 which communicates the first fluid pressure chamber 13 of the master cylinder 4 with the stroke simulator 5 comprises a port 50 (described later) formed at a bottom end of the fitting opening 41 of the cylinder body 10, a fluid passage 51 in the opening/closing means 7 and a fluid passage 52 formed in the simulator body 40 (FIGS. 3 and 7).

As indicated in FIG. 1, the simulator body 40 of the stroke simulator 5 includes a bore 44 having an end wall. A piston 46 is slidably provided in the bore 44 through a cup seal 45. A pressure chamber S is defined between a forward end (an end for insertion into the bore 44) of the piston 46 and the end wall of the bore 44, which pressure chamber is sealed by the cup seal 45. The fluid passage 52 forming the simulator passage 6 opens into the pressure chamber S. The large-diameter portion 40*c* of the simulator body 40 has a hollow portion. The bore 44 is extended so as to form a cylindrical extension 44*a* in the hollow portion of the large-diameter portion 40*c*. The large-diameter portion 40*c* of the simulator body 40 has an open end on a side opposite to the small-diameter portion 40*a*. The open end of the large-diameter portion 40*c* is closed by a cover plate 40'. A spring bearing 48 is provided at a distal end of the cylindrical extension 44*a* of the large-diameter portion 40*c*, so as to face the cover plate 40'. A first spring 47 is disposed between the spring bearing 48 and the cover plate 40'. One end of the first spring 47 is seated on the cover plate 40'. The other end of the first spring 47 is received by the spring bearing 48. Further, a second spring 49 having a smaller spring force than the first spring 47 is provided inside the cylindrical extension 44*a*. The second spring 49 is interposed between the spring bearing 48 and a cup-like surface of the piston 46 and normally biases the piston 46 in an upward direction. In the stroke simulator 5, when the fluid pressure in the pressure chamber S rises, the piston 46 first moves downward against the spring force of the second spring 49 and abuts against the spring bearing 48. Thereafter, the piston 46 moves downward against the spring force of the first spring 47.

As is clearly shown in FIGS. 7 to 10, the opening/closing means 7 comprises a poppet valve 54 for opening and closing the fluid passage 52 (the simulator passage 6) in the simulator body 40 and a rocking lever 55 which is movable together with the secondary piston 12 in the master cylinder 4 to open and close the poppet valve 54. The poppet valve 54 and the rocking lever 55 are assembled in a casing 56, to form a unit. To assemble the simulator body 40 to the fitting opening 41 of the boss portion 42 of the cylinder body 10, the unit is connected between the cylinder body 10 and the simulator body 40 through a washer 57. As indicated in FIG. 8, the port 50 forming the simulator passage 6 on a side of the cylinder body 10 has an oblong (non-circular) form, which extends in an axial direction of the bore 14 of the cylinder body 10. The casing 56 includes a C-shaped projection 56*a* projected upwardly therefrom. The C-shaped projection 56*a* is fitted into the oblong port 50 while being located close to the front side (on a side of the closed end of the bore 14) of the oblong port 50. Thus, by means of the oblong port 50, the casing 56 is prevented from rotating.

The poppet valve 54 comprises a valve seat 61, a valve body 62 adapted to move to and away from the valve seat 61 and a valve spring 63 which normally biases the valve body 62 in a direction for closing the valve. The valve seat 61 is formed at the bottom of a recess 60 formed in the simulator body 40, so as to surround an opening of the fluid passage

52. The fluid passage **52** is closed when the valve body **62** is seated on the valve seat **61**, and is open when the valve body **62** is separated from the valve seat **61**. The valve spring **63** has one end engaged with the casing **56**, and normally biases the valve body **62** in the direction for closing the valve. The valve body **62** is slidably fitted into a through-hole **56***b* formed in the casing **56**, with a lower end thereof being connected to an elastic member **64** capable of intimate contact with the valve seat **61**. An upper end portion of the valve body **62** includes a constricted portion **62***a* engageable with the rocking lever **55**. The fluid passage **51** in the opening/closing means **7**, which forms the simulator passage **6**, is an inclined passage formed in the casing **56**, with one end thereof opening into the through-hole **56***b*. Therefore, when the poppet valve **54** is open, as shown in FIG. **7**, brake fluid in the first fluid pressure chamber **13** of the master cylinder **4** is supplied to the stroke simulator **5** through the port **50** in the cylinder body **10**, the fluid passage **51** in the casing **56**, the recess **60** around the valve body **62** and the fluid passage **52** in the simulator body **40**. The material of the elastic member **64** is not particularly limited, as long as it is capable of intimate contact with the valve seat **61**. Various materials, such as rubber, resin, etc., may be used for the elastic member **64**.

As is clearly shown in FIG. **9**, the rocking lever **55** comprises a shaft portion **65** supported by a shaft bearing portion formed in the casing **56**, a claw portion **66** extending radially outwardly from the shaft portion **65** and a columnar portion **67** extending from the shaft portion **65** substantially at a right angle relative to the claw portion **66**. The claw portion **66** is engageable with the constricted portion **62***a* of the valve body **62**. When the rocking lever **55** is supported by the casing **56**, an upper end of the columnar portion **67** of the rocking lever **55** extends through the port **50** of the cylinder body **10** into the bore **14**. A rear end portion of the secondary piston **12** includes an annular groove **68**. The upper end of the columnar portion **67** is positioned within the annular groove **68**.

When the secondary piston **12** is located at the retracted position, a front wall surface **69** of the annular groove **68** is positioned close to the rear side of the oblong port **50**. In this state, the columnar portion **67** of the rocking lever **55** is rotated by the front wall surface **69** in a clockwise direction in FIG. **7**, and finally abuts against the front wall surface **69** and maintains an upright position (FIG. **7**). Consequently, the valve body **62** of the poppet valve **54** is lifted by the claw portion **66** and, as shown in FIG. **7**, the fluid passage **52** (the simulator passage **6**) on a side of the stroke simulator **5** is opened. When the secondary piston **12** advances from the retracted position, the front wall surface **69** moves in a leftward direction in FIG. **7**, to thereby release the force of the rocking lever **55** lifting the valve body **62** of the poppet valve **54**. Since the valve body **62** is biased in the valve-closing direction by means of the valve spring **63**, the rocking lever **55** rocks about the shaft portion **65**, and the fluid passage **52** is closed, as shown in FIG. **10**.

As shown in FIGS. **1** and **3**, the stroke sensor **8** is provided in a cover **70** connected to a flange portion **10***a* at the rear end portion of the cylinder body **10**. The stroke sensor **8** comprises a sensor body **71** containing a rotation angle detector (not shown), a rotary shaft **72** extending from the rotation angle detector downward beyond the lower surface of the sensor body **71**, a sensor arm **73** having one end fixedly connected to the rotary shaft **72**, and a sensor pin **75**. The sensor pin **75** extends upward from the rear end of the primary piston **11** and extends through a slit **74** formed in the piston guide **23** toward the sensor body **71**.

As is clearly shown in FIG. **11**, an oblong hole **76** is formed in the other end of the sensor arm **73**. An upper end portion of the sensor pin **75** is inserted into the oblong hole **76**. The sensor pin **75** is adapted to linearly move, together with the primary piston **11**, in the slit **74** formed in the piston guide **23**. The oblong hole **76** of the sensor arm **73** has a length sufficient for ensuring a linear movement of the sensor pin **75**, and has a width sufficient for ensuring a smooth motion of the sensor pin **75**. The sensor arm **73** is biased in a counterclockwise direction as viewed in FIG. **11**, by means of a biasing means (not shown). By this arrangement, a wall surface **76***a* on one side of the oblong hole **76** is always pressed against the sensor pin **75**. That is, the sensor pin **75** is adapted to perform linear movement without play in the oblong hole **76** of the sensor arm **73**. Therefore, an amount of linear movement of the primary piston **11** can be accurately converted to an amount of rotation of the rotary shaft **72**. In this case, as indicated by a solid line in FIG. **14**, a substantially linear relationship exists between the amount of linear movement of the primary piston **11** and the angle of rotation of the rotary shaft **72**, as a result of which accurate sensing can be stably conducted over an entire length of a stroke.

Instead of the sensor arm **73** having a straight form shown in FIG. **11**, a V-shaped sensor arm **73**' as shown in FIG. **12** or a curved sensor arm **73**" as shown in FIG. **13** may be employed.

The sensor arm **73**' is bent in a direction outward relative to a line connecting the rotary shaft **72** and the sensor pin **75**, and the sensor arm **73**" is curved outward relative to the line connecting the rotary shaft **72** and the sensor pin **75**. In the sensor arm **73**", the oblong hole **76** is also curved. When the V-shaped sensor arm **73**' is used, as indicated by a dotted line in FIG. **14**, high resolution can be obtained during early periods of a stroke while resolution near the end of the stroke is somewhat compromised. When the curved sensor arm **73**" is used, as indicated by a one-dot chain line in FIG. **14**, a resolution obtained is intermediate between those of the sensor arms **73** and **73**'. However, the relationship between the angle of rotation and the stroke becomes linear, with the result that data processing using a sensor output can be easily conducted.

Hereinbelow, an operation of the master cylinder apparatus **1** is described. The master cylinder apparatus **1** is connected to a vehicle body using a stud bolt **80**. The stud bolt **80** extends from a front side of the flange portion **10***a* of the cylinder body **10** through the cover **70** that accommodates the stroke sensor **8**.

First, when the BBW system is normally operated, the fail-safe valves **2**A and **2**B are closed. Therefore, dependent on a force applied to the brake pedal **3**, the primary piston **11** advances in a leftward direction as viewed in FIGS. **1** and **3**, and a fluid pressure corresponding to the input from the brake pedal **3** is generated in the first fluid pressure chamber **13**. In this instance, the poppet valve **54** of the opening/closing means **7** is open due to engagement with the secondary piston **12** at the retracted position (FIG. **7**). Therefore, the brake fluid in the first fluid pressure chamber **13** passes through the port **50** of the cylinder body **10**, the fluid passage **51** in the opening/closing means **7** and the fluid passage **52** in the simulator body **40** and is supplied to the pressure chamber S in the stroke simulator **5**.

Although the secondary piston **12** marginally advances in accordance with the rise in pressure in the first fluid pressure chamber **13**, the poppet valve **54** is not caused to close as a result of this movement of the secondary piston **12**.

When brake fluid is introduced into the pressure chamber S of the stroke simulator **5**, the piston **46** first moves downward against the spring force of the second spring **49** having a force smaller than that of the first spring **47**, so as to ensure an appropriate initial stroke of the brake pedal **3**. After the piston **46** abuts against the spring bearing **48**, the piston **46** moves downward against the spring force of the first spring **47**, which is larger than that of the second spring **49**, to thereby ensure a desired stroke of the brake pedal **3**. As the piston **46** moves downward, a reactive force acting on the brake pedal **3** increases. In this way, a so-called pedal resistance is generated, to thereby obtain an optimum pedal-feel. Meanwhile, the amount of movement of the primary piston **11** is monitored by the stroke sensor **8**. Based on a signal emitted from the stroke sensor **8** (a piston stroke), the electronic control unit in the BBW system controls the fluid pressure supplied to the wheel cylinders, to thereby obtain a desired braking force.

The braking force is controlled on the basis of a piston stroke in the above-mentioned manner. Thus, if a fluid is caused to repeatedly flow from behind the cup seal **35** to the first fluid pressure chamber **13** (a backside flow) under repetitive operation of the brake pedal **3**, a reactive force acting on the brake pedal **3** increases, which makes it difficult to obtain an appropriate braking force in correspondence with operation of the brake pedal. However, in this embodiment, as indicated in FIG. **5**, the outer circumferential edge of the primary-side cup seal **35** abuts against the front wall surface **38***a* of the annular groove **38**, thus preventing the backside flow. Therefore, there is no flow of fluid from behind the primary-side cup seal **35** to the first fluid pressure chamber **13**, so that a desired braking force can be stably obtained, even when the brake pedal **3** is repeatedly operated.

Next, description is made with regard to an operation of the master cylinder apparatus **1** in the event of failure of the BBW system. In this case, the fail-safe valves **2**A and **2**B are opened, and the master cylinder **4** is fluidly connected to the wheel cylinders. Then, the primary piston **11** advances in accordance with a force applied to the brake pedal **3**, so as to increase a fluid pressure in the first fluid pressure chamber **13**. The brake fluid in the first fluid pressure chamber **13** flows from the first discharge port **16** through the fail-safe valve **2**A to the corresponding wheel cylinders. On the other hand, the secondary piston **12** also advances according to an increase in the fluid pressure in the first fluid pressure chamber **13**, and brake fluid in the second fluid pressure chamber **15** is supplied from the second discharge port **17** through the fail-safe valve **2**B to the corresponding wheel cylinders.

As the secondary piston **12** advances, as indicated in FIG. **10**, the rocking lever **55** of the opening/closing means **7** rocks about the shaft portion **65**, and the valve body **62** of the poppet valve **54** is seated on the valve seat **61**, to thereby close the fluid passage **52** (the simulator passage **6**) in the simulator body **40**.

Consequently, the supply of brake fluid to the stroke simulator **5** is stopped; and as a result, the master cylinder apparatus **1** operates as a manual brake, and supplies a desired amount of brake fluid to each of the wheel cylinders.

In this state, the fluid pressure in the first fluid pressure chamber **13** acts on the rear side of the valve body **62** of the poppet valve **54**. Therefore, the poppet valve **54** reliably closes the simulator passage **6**, with the aid of the elastic member **64** connected to the lower end thereof. When the BBW system is normally operated, the valve body **62** of the poppet valve **54**, which is in a standby condition, is suspended at a position separate from the valve seat **61**. Therefore, if the valve body **62** is placed in a standby condition for a prolonged period of time, the elastic member **64** will not be subject to deformation or damage, and the simulator passage **6** can consequently be reliably closed in the event of failure of the system.

When the brake pedal **3** is released, since the spring force of the second return spring **21** is larger than that of the first return spring **20**, the secondary piston **12** is first retracted, thus lowering a fluid pressure in the second fluid pressure chamber **15**. Consequently, the brake fluid returns from the wheel cylinders to the second fluid pressure chamber **15**, while the brake fluid is supplied from the reservoir **29** through the cup seal **37** to the second fluid pressure chamber **15**. The secondary piston **12** finally abuts against the stopper pin **25**. Thus, a retracted position of the secondary piston **12** is limited, and the secondary piston **12** is stopped at its initial position. In this instance, the second fluid pressure chamber **15** and the reservoir **29** are communicated with each other through the supply port **33** formed in the cup-like portion **12***a* of the secondary piston **12**, to thereby control the brake fluid in the second fluid pressure chamber **15**. On the other hand, under the spring force of the first return spring **20**, the primary piston **11** returns to its initial position later than the secondary piston **12**. Consequently, the first fluid pressure chamber **13** and the reservoir **29** are communicated with each other through the supply port **32** formed in the cup-like portion **11***a* of the primary piston **11**, to thereby control the brake fluid in the first fluid pressure chamber **13**. As described above, the cup seal **35** on a side of the primary piston **11** is configured to prevent the backside flow (FIG. **5**). Therefore, no brake fluid is supplied from the reservoir **29** to the first fluid pressure chamber **13** during a return stroke of the primary piston **11**. Thereafter, when the brake pedal **3** is operated, the primary piston **11** and the secondary piston **12** advance again. At this time, an invalid stroke is not generated, since the primary piston **11** and the secondary piston **12** are accurately returned to their initial positions by means of the piston guide **23** and the stopper pin **25**. Therefore, stable braking can be conducted, even in the event of failure of the BBW system.

In this embodiment, the opening/closing means **7** is provided in the simulator passage **6** directly extended from the cylinder body **10** of the master cylinder **4** to the stroke simulator **5**. Therefore, there is no need to provide an extra valve element inside the secondary piston **12**, thus achieving a reduction in size of the secondary piston **12**. In this embodiment, the opening/closing means **7** comprises the poppet valve **54**. Therefore, it is unnecessary to use a seal member, with concomitant risk of damage, and the opening/closing means **7** can be stably operated over a prolonged period of time. This markedly improves reliability of the apparatus in the event of failure of the BBW system. Further, the poppet valve **54** is opened and closed by the rocking lever **55** which moves together with the secondary piston **12**. Therefore, no special drive means is necessary for operating the poppet valve **54**, which simplifies a structure of the opening/closing means **7**. Further, in this embodiment, the stroke sensor **8** has a mechanism such that a linear motion of the primary piston **11** is converted to a rotational motion through engagement between the sensor pin **75** and the sensor arm **73**. Therefore, the stroke sensor **8** is made simple in structure and is reduced in size, which results in an overall reduction in size of the entire apparatus.

A structure of the opening/closing means **7** is not particularly limited. Instead of the poppet valve **54** in the above-mentioned embodiment, a tilt valve, a slide valve or a spool valve may be used.

In the above-mentioned embodiment, use is made of a master cylinder in which the second return spring **21** for the secondary piston **12** has a larger spring force than the first return spring **20** for the primary piston **11**. However, this does not limit the present invention. The master cylinder may be such that the first return spring **20** for the primary piston **11** has a larger spring force than the second return spring **21** for the secondary piston **12**. In this case, since the retracted position of the secondary piston **12** is limited by the stopper pin **25**, it is possible to avoid a phenomenon such that when the brake is released the secondary piston **12** travels an excessive distance, i.e., overshoot.

Although only some exemplary embodiments of this invention have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teaching and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention.

The entire disclosure of Japanese Patent Application No. 2003-341338 filed on Sep. 30, 2003 including specification, claims, drawings and summary is incorporated herein by reference in its entirety.

What is claimed is:

1. A master cylinder apparatus comprising:

a tandem-type master cylinder adapted to be connected to wheel cylinders through fail-safe valves; and

a stroke simulator for ensuring a desired stroke of a brake pedal upon receiving a brake fluid introduced from a primary-side fluid pressure chamber formed in the master cylinder,

wherein:

the tandem-type master cylinder comprises:

a cylinder body;

a primary piston and a secondary piston arranged in an axial direction of the cylinder body and being capable of sliding movement in the cylinder body;

the primary-side fluid pressure chamber, which is defined between the primary piston and the secondary piston;

a secondary-side fluid pressure chamber defined between the secondary piston and the cylinder body;

a first circumferential groove and a second circumferential groove formed in an inner surface of a bore of the cylinder body, the first circumferential groove and the second circumferential groove being spaced apart from each other in the axial direction of the cylinder body;

a first cup seal provided in the first circumferential groove and adapted to seal an outer circumferential surface of the primary piston;

a second cup seal provided in the second circumferential groove and adapted to seal an outer circumferential surface of the secondary piston;

a first return spring provided in the primary-side fluid pressure chamber so as to bias the primary piston in a direction for retraction;

a second return spring provided in the secondary-side fluid pressure chamber so as to bias the secondary piston in the direction for retraction; and

a limiting means provided in the cylinder body so as to limit a retracted position of the secondary piston.

2. A master cylinder apparatus according to claim **1**, wherein the second return spring for biasing the secondary piston has a larger spring force than the first return spring for biasing the primary piston.

3. A master cylinder apparatus according to claim **1**, wherein the limiting means comprises a stopper pin which extends across the bore of the cylinder body, the stopper pin being provided in an oblong hole extending through the secondary piston.

4. A master cylinder apparatus according to claim **2**, wherein the limiting means comprises a stopper pin which extends across the bore of the cylinder body, the stopper pin being provided in an oblong hole extending through the secondary piston.

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